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CI Controls for Energy and Environment

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INTRODUCTION

Computational intelligence (CI) is a rapidly evolving field that utilizes life imitating metaphors for guiding model building including, but not limited to neural networks, fuzzy logic, genetic algorithms, artificial life, and hybrid CI paradigms. Although the boundaries between artificial intelligence (AI) and CI are not distinct, their research communities are separate and distinct. CI researchers tend to focus on processing numerical data from sensors, while the AI community generally relies on symbolic computing to capture human knowledge. In both areas, there is a great deal of interest and activity in hybrid systems that can offset the limitations of individual methods, extend their capabilities, and create new capabilities. Examples of the benefits that can accrue from hybrid systems are contained in Ref. 1, and illustrated in Fig. 1.

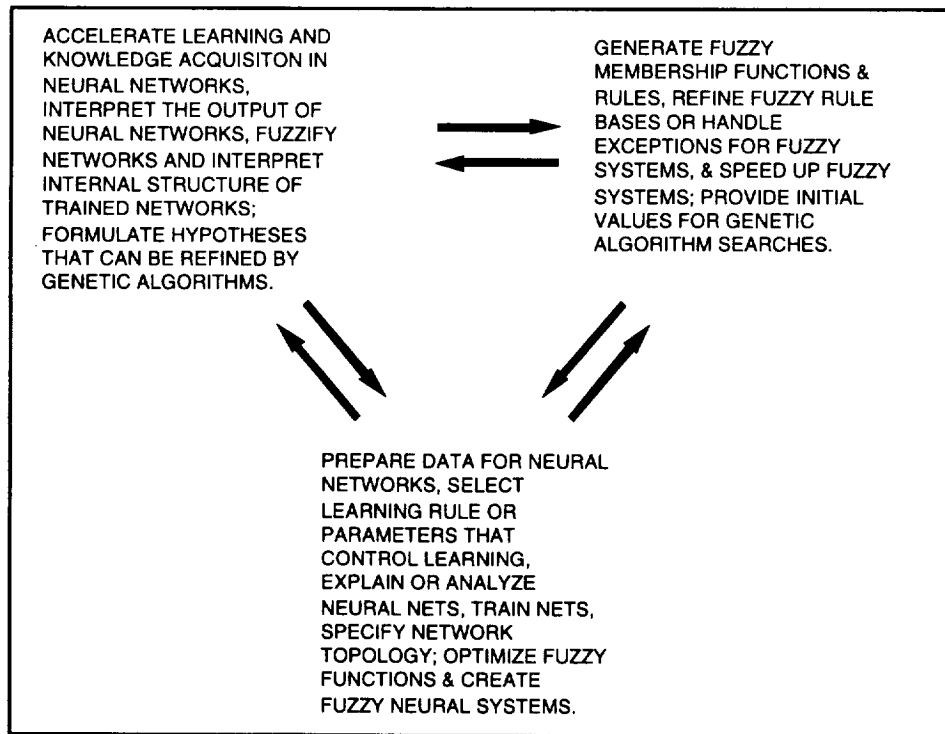


Figure 1

The contribution of fuzzy logic, neural networks, and genetic algorithms are listed clockwise starting in the upper left-hand corner of the figure. Useful synergy can also result from combinations with non-CI methods, e.g., combining neural networks and statistical techniques.

CI paradigms have been utilized successfully in a myriad of applications and many different application areas. Among the first to receive attention was the control of nonlinear systems. Nonlinear, multivariable systems continue to be a challenging area with potentially high payoffs as recently noted by Narendra and Mukhopadhyay (see Ref. 2):

It is well known that the control of complex nonlinear systems, even when the nonlinear equations describing the plant are known, is a very difficult problem. It becomes truly formidable when the functions are unknown. However, such problems are arising in industrial applications with increased frequency. In numerous recent applications such as manufacturing, space technology, and robotics, as well as established areas such as process control and aircraft control, there is a growing need for methods to control systems that are distinctly nonlinear. Many of the truly difficult problems also have several variables of interest. In fact, it is safe to say that the most (intelligent) control problems related to complex dynamical systems in the future will be both multivariable and nonlinear in nature.

Japan was quick to realize benefits from applications in energy and environment. For example, hybrid systems utilizing fuzzy control techniques for ventilation installed in 1988 in the Fukuchiyama and Kongosan tunnels proved effective in accurately controlling ventilation and providing energy cost savings of as much as 30% (see Ref. 3). In the U.S., the National Science Foundation (NSF) initiated in 1992 a broad research program in intelligent controls. Pioneering applications in the electric utility industry have resulted from studies jointly funded by the NSF and the Electric Power Research Institute's (EPRI) Exploratory Research in Adaptive Control Systems Program (see Ref. 4). Another important U.S. activity is the Environmental Protection Agency's (EPA) Adaptive Controls System Research Program for Pollution Prevention, and Clean Technologies (see Ref. 5). Recently, the U.S. Department of Energy (DOE) sponsored the first of a series of meetings to accelerate the transfer of CI technology to energy and environmental systems by bringing together individuals from the controls systems and CI communities to focus attention on potential benefits to be derived from the application of intelligent adaptive controls. The benefits of interest to DOE include: improved energy efficiency, extending natural resources, reducing and/or preventing pollution, increasing safety, increasing reliability and availability, extending service life, increasing exports, and advancing the technology base with relatively small capital investments (see Ref. 6).

This Workshop on Computational Intelligence and Its Impact on Design/Fabrication and Operation of Future High Performance Engineering Systems provides an opportunity to reflect on issues that need to be resolved and initiatives that could contribute to the transfer of CI technology for energy and environmental applications. This paper briefly identifies some issues and initiatives with a focus on four areas: education, deployment, standardization, and development.

ISSUES AND INITIATIVES

There are enormous potential benefits to be derived from increasing the efficiency of energy conversion and reducing or preventing its emissions. Many of these benefits could be achieved by applications of CI technology in areas such as intelligent control systems. These applications could, in turn, serve to advance the technology and thereby contribute to applications in other areas as well. The current emphasis of engineering work and research on economic strength and environmental preservation, provides opportunities for accelerating the deployment of CI technology. The resolution of some key issues could contribute to that goal.

Education

Educational initiatives can contribute in important ways to the accelerated utilization of new technology. At the college level, the acquisition of knowledge and skills in CI tools and techniques can

create the foundations for a skilled work force of applications professionals, and provide a new generation of graduate students who could contribute to future advances. This can be facilitated by introducing CI in core courses and in standard textbooks, and presenting it in elective courses in the context of integrated systems. The interdisciplinary nature of energy and environmental systems lends itself well to the interdisciplinary student project teams that are being formed as a result of recent revisions in engineering curricula.

Some vendors offer high quality intensive short courses on the use of their products; this can be an effective way to train professionals, assuming that the products were previously selected for prospective applications from among competing alternatives. This catch-22 does not have any obvious solution but does suggest some useful initiatives. For example, comprehensive, independent product reviews could perhaps be performed in academic laboratories. Benchmarks and other performance measures could also be generated in academic institutions in concert with standardization initiatives of professional societies.

Reluctance to utilize new technology is often due to misinformation or the lack of information. For example, Zadeh notes that the control systems community needs to learn the merits of task oriented control, used with or in place of set-point control, and Goldberg cites potential users' lack of understanding of what genetic algorithms are good for and lack of awareness of the new integrated theory of operations (see Ref. 6). A traditional way to remedy these situations is through educational activities conducted by professional societies. Other forums such as this workshop, can also be effective.

Reluctance to utilize new technology is often due to lack of attention by developers to users' needs and constraints. Developers could profit from on-the-job training situations. Sophisticated tools that require expert tailoring for different applications are not likely to succeed as stand-alone products and may need to be marketed as part of a professional services package. This approach also provides opportunities to refine the product through direct interaction with the users. Direct interactions might also be useful at the other extreme where the product appears to the developer to be easy to use in many different problem situations, but is not being utilized due to unanticipated obstacles that the developer has not encountered. Developers would probably find many opportunities to better test products, build prototypes, and engage in other mutually beneficial collaborative activities with investigators in the energy and environment community.

Deployment

Excessive hype creates unrealistic expectations. It can delay development and impede market penetration. Bezdek's graph (Fig. 2) clearly illustrates the role of hype in the development of new technologies (Ref. 7). Historically, much of the hype surrounding both AI and CI technology has involved irrelevant claims regarding biological plausibility and attempts to characterize the technology as the one approach to solve all problems. The overreaction to AI hype is familiar to most observers and it has been so severe that recently one of its leading advocates acknowledged that "bad press" has made most of the Fortune 1,000 companies that use AI reluctant to admit it.

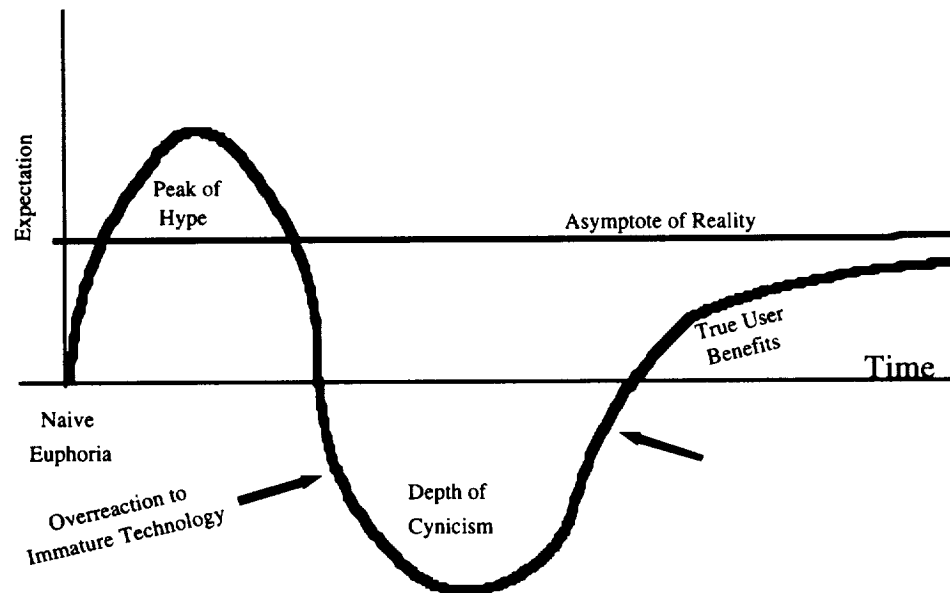


Figure 2

CI technology appears thus far to have achieved a better balance between expectations and benefits. For example, in the discussion of the curve (Fig. 2), Bezdek writes, "The ones that survive do so because someone finds a good use (=true user benefit) for the basic idea," and in justifying the need for a new journal in the first issue of the *IEEE Transactions on Fuzzy Systems*, Bezdek cites "... the enormous success of commercial applications which are at least partially dependent on fuzzy technologies fielded (in the main) by Japanese companies has led to a surge of curiosity about the utility of fuzzy logic for scientific and engineering applications." He also says "...interest in fuzzy models was not really very widespread until their utility in fielded applications became apparent." It is clear that a reasonable approach to accelerate technology transfer is to guard against damaging hype while attempting to deploy many highly visible, successful applications, especially those that demonstrate unique capabilities or provide exemplars in new applications areas.

Many, if not most, of the physical applications of CI technology do not achieve much visibility. Most applications are "reported" but not published. Vendors often cannot or will not provide details concerning their client's commercial applications. Historically, journals devoted to applications tend to publish benchmark problems and rarely cover commercial applications. While this practice is likely to continue due to proprietary considerations and other practical reasons, it is interesting to note that applications in energy and environment, particularly those that create public benefits, could offer firms opportunities to accrue additional benefits from advertising their successes that add to the returns on their investments.

Standardization

Standardization seems to occur naturally as technologies mature and it can contribute to accelerated deployment. It can also contribute to accelerated development. For example, Zadeh underscores the need for standardization of fuzzy logic syntax, taxonomy, and semantics (see Ref. 6). While CI

technology is probably far from the state ascribed in *Genesis* as leading to the failure of the Tower of Babel project, the unbridled creativity of its inventors and users has contributed to the need to deal with cultural differences that create barriers to its utilization by potential users in established disciplines. This is important because CI technology is most likely to be deployed as components of integrated systems.

To ensure the deployment of any new technology, there is a need for meaningful performance evaluations, whether employed in fixed, off-the-shelf packages or individually constructed for tailor-made solutions, and that need is facilitated by standardization. Universities, technical societies, and institutional users could accelerate this process through a coordinated effort. Participation in standardization activities provides substantial opportunities for technology transfer.

Standardization is important for applications in energy and environment. The Department of Energy sponsors annual workshops to communicate information related to standards through the technical standards community. In 1995 DOE's Technical Standards Program Workshop was held on October 3–6, at the Adam's Mark Hotel in St. Louis. The goal of this year's workshop was to inform the technical standards community of strategic standardization activities taking place within the Department, in other government agencies, standards-developing organizations, and industry.

Development (User-Oriented)

As indicated at the beginning of this paper, hybridization offers the potential to offset the limitations of individual methods, and some of the development needs of each of three CI paradigms can be readily identified from Fig. 1. Without exception, each of the hundreds of papers on hybrid systems reviewed by this author describes the technical limitations of at least one paradigm. Clearly, the need for additional technical developments is well documented and it is beyond the scope of this paper to review those needs. Instead, the aim here is to provide a perspective on some technology development needs that could accelerate deployment, and lead to more applications in energy and environment, particularly in control systems that are expected to provide significant public benefits.

The large body of literature and numerous successful commercial applications of neurocontrol and fuzzy control attest to the availability and efficacy of these methods. Genetic algorithms do not yet have a comparable track record, but their utility in stand-alone and hybrid applications has been demonstrated. Despite this progress, additional efforts aimed at design automation could contribute substantially to accelerated deployment. Priority should be given to developing more robust and easier to use tool kits for CI technology (including hybrids), and systematic design procedures for intelligent adaptive control systems.

Verification and validation is a difficult and controversial area. The difficulty, as indicated by Wildberger (see Ref. 8), is that introducing methods that allow a control system to adapt or learn while it is operating creates new and perhaps unsolvable quality assurance problems. This difficulty is regarded by some as academic but it certainly creates issues of practical importance in regulatory situations, particularly nuclear power plants, where it is a show-stopper. Viewed in the context of an agenda for accelerating deployment, it is reasonable to speculate that some of the controversy might be dissipated with more experience from intelligent control systems, in applications such as fossil fueled power plants and environmental control systems. Interestingly, the foundation for many applications in this area rests upon prior research and development efforts in nuclear power applications.

SUMMARY AND CONCLUSIONS

This is a propitious time to accelerate the transfer of CI technology to the energy and environment communities. CI technology is available today that could be utilized in many applications in energy and environment. Substantial public benefits and returns on investments would accrue from the accelerated

deployment and the expanded experience base could result in technological advances in other areas. These goals can be achieved by well managed strategic alliances.

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